

Research article

## Physiological, biomechanical and anthropometrical predictors of sprint swimming performance in adolescent swimmers

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### Abstract

The purpose of this study was to analyze the relationships between 100-m front crawl swimming performance and relevant biomechanical, anthropometrical and physiological parameters in male adolescent swimmers. Twenty five male swimmers (mean  $\pm$  SD: age  $15.2 \pm 1.9$  years; height  $1.76 \pm 0.09$  m; body mass  $63.3 \pm 10.9$  kg) performed an all-out 100-m front crawl swimming test in a 25-m pool. A respiratory snorkel and valve system with low hydrodynamic resistance was used to collect expired air. Oxygen uptake was measured breath-by-breath by a portable metabolic cart. Swimming velocity, stroke rate (SR), stroke length and stroke index (SI) were assessed during the test by time video analysis. Blood samples for lactate measurement were taken from the fingertip pre exercise and at the third and fifth minute of recovery to estimate net blood lactate accumulation ( $\Delta$ La). The energy cost of swimming was estimated from oxygen uptake and blood lactate energy equivalent values. Basic anthropometry included body height, body mass and arm span. Body composition parameters were measured using dual-energy X-ray absorptiometry (DXA). Results indicate that biomechanical factors (90.3%) explained most of 100-m front crawl swimming performance variability in these adolescent male swimmers, followed by anthropometrical (45.8%) and physiological (45.2%) parameters. SI was the best single predictor of performance, while arm span and  $\Delta$ La were the best anthropometrical and physiological indicators, respectively. SI and SR alone explained 92.6% of the variance in competitive performance. These results confirm the importance of considering specific stroke technical parameters when predicting success in young swimmers.

**Key words:** oxygen uptake, stroke index, energy cost, front crawl.

### Introduction

Certain anthropometric characteristics must be taken into consideration in analysing sprint swimming performance, including body height, arm span and lean body mass (Jürimäe et al., 2007; Strzala and Tyka, 2009). These somatic attributes are largely inherited and determine swimming technique to a high degree. However, data on the relationship among anthropometric properties, physical capacity and sprint swimming performance in adolescent swimmers are scarce. Since metabolic capacities as well as skill acquisition, are affected by growth and development (Malina, 1994), it can be suggested that factors predicting swimming performance may vary for young

swimmers and may be different compared to adults. In fact, Geladas et al. (2005) found that total upper extremity length, leg power and handgrip strength could be used as predictors of 100-m front crawl performance in 12-14 year-old boys. A multivariate analysis of swimming performance in a large sample ( $n = 66$ ) of male swimmers (11-12 years) of high national level found that predictive variables pertaining to the anthropometric (sitting height), physiological (aerobic speed and endurance) and technical (swimming index) domains explained 82.4% of competitive performance (Saavedra et al., 2010). Overall, it appears that somatic traits play an important role in swimming performance during the years of growth.

Energy cost is a key parameter to evaluate performance in swimming and it has been described as a predictor of performance in human locomotion, in both terrestrial and aquatic environments (di Prampero, 1986; Zamparo et al., 2005b). Traditionally, the energy cost of swimming ( $C_s$ ) is defined as the total energy expenditure required for displacing the body over a given unit of distance (di Prampero et al., 1986; Pendergast et al., 2003). Kjendlie et al. (2004a) reported significantly lower energy cost in children (12-year-old boys) than in adults (21-year-old males) at comparable swimming velocity, thus confirming the results obtained by Ratel and Poujade (2009) in a group of 12-13 year-old boys and 18-22 year old men.  $C_s$  increases as a function of velocity (Capelli et al., 1998; Poujade et al., 2002) and has usually been assessed from the ratio of oxygen uptake ( $VO_2$ ) to the corresponding velocity ( $v_s$ ) in swimmers (Kjendlie et al., 2004a). When calculating  $C_s$  based in the  $VO_2$  and velocity, there are two ways to computing that. Some researchers use  $VO_2 \cdot v^3$  to illustrate  $C_s$  with linear function (Kjendlie et al., 2004a; 2004b), but the common use is  $VO_2 \cdot v$  (curvilinear function) (Barbosa et al., 2008; Capelli et al., 1998; Poujade et al., 2002; Zamparo et al., 2005a). However, it is also important that anaerobic metabolism is also taken into account (Barbosa et al. 2005b, Barbosa et al., 2006), since its relatively higher contribution during 100-m distance.

The recent development of improved instrumentation and technology in breath-by-breath analysis has resulted in new approaches to study  $VO_2$  also in aquatic environments. The last generation of miniaturized breath-by-breath metabolic carts can be used in combination of newly developed snorkels to directly measure cardiorespiratory parameters during swimming with acceptable accu-

racy and reliability (Keskinen et al., 2003; Rodriguez et al., 2008). This instrumentation has also been used to characterize  $\text{VO}_2$  kinetics during free swimming (Barbosa et al., 2006; Rodriguez et al., 2003). However, no studies using breath-by-breath gas analysis have been conducted to determine oxygen consumption and  $C_s$  during sprint swimming in adolescent swimmers.

The understanding of the behavior of stroke mechanics and its relationship to  $v_s$  is one of the major points of interest in biomechanical research in swimming (Keskinen and Komi, 1993; Kjendlie et al., 2006; Toussaint et al., 2006). Increases or decreases in  $v_s$  are due to a combined increase or decrease in stroke rate (SR) and stroke length (SL) (Keskinen and Komi, 1993; Toussaint et al., 2006). Stroke mechanics is considered to reach an optimal balance between SR and SL when  $v_s$  values are at their highest level with a relatively low  $C_s$  (Barbosa et al., 2008). It has been shown that increases in maximal  $v_s$  from the age of about 11 are related to increased SL, while SR at maximal  $v_s$  does not increase with age (Kjendlie et al., 2004b). According to the literature, at a given  $v_s$ ,  $C_s$  significantly increases with increasing SR (Barbosa et al., 2005a; Zamparo et al., 2005b). Less consistent is the decrease of  $C_s$  with increasing SL (Barbosa et al., 2005a; Costill et al., 1985; Pendergast et al., 2003; Zamparo et al., 2005b). High stroke index (SI) values are strongly associated with low  $C_s$  (Costill et al., 1985). In this sense, and following the referred authors, SI can also be used as an overall estimation of swimming efficiency.

To our knowledge, no studies have investigated the influence of different anthropometric, physiologic and technical parameters together to determine sprint swimming performance in young swimmers. There is also lack of studies using breath-by-breath technology, and thus being able to characterize oxygen consumption, in during swimming in adolescent swimmers. Accordingly, the purpose of this study was to investigate the contribution of different anthropometrical, physiological and biomechanical parameters to sprint swimming performance in adolescent boys. We hypothesis that sprint swimming performance at that young age could be predicted from a relatively low number of selected variables pertaining to these three testing domains.

## Methods

### Participants

Twenty-five adolescent male swimmers ( $15.2 \pm 1.9$  years) participated in the study. All swimmers had a training background of  $5.6 \pm 1.5$  years and over the last two years they had been practicing for  $5.6 \pm 1.5$  h/week. Swimmers were recruited from local swimming clubs on a voluntary basis. Biological age was measured according to the method of Tanner (Tanner and Whitehouse, 1976), which uses self-assessment of genitalia development and pubic hair stage in boys. The participants were given photographs, figures and descriptions, and asked to choose the one that most accurately reflected their appearance. This study was approved by the Medical Ethics Committee of the University of Tartu. All swimmers and their parents were informed of the purposes and methods of the study

and a written informed consent was obtained from the parents before participation.

### Procedures

Test and assessments were conducted on two different occasions during the study period. On a first visit, anthropometrical parameters and biological age were assessed. The same day, a second testing session consisted of an all-out 100-m front crawl swimming test in the pool. On a second day, body composition parameters were measured.

### Anthropometry and body composition

Body height was measured to the nearest 0.1 cm using a Martin's anthropometer, body mass (kg) was measured to the nearest 0.05 kg using calibrated medical balance scales (A&D Instruments Ltd., UK), and body mass index (BMI;  $\text{kg}\cdot\text{m}^{-2}$ ) was then calculated. In addition, arm span was measured to the nearest 0.1 cm. Anthropometrical assessments were performed by internationally certified ISAK level 1 anthropometrist.

Body fat mass (kg), fat-free mass (kg), bone mass (kg), total bone mineral density ( $\text{g}\cdot\text{cm}^{-2}$ ) and spine (L1-L4) bone mineral density ( $\text{g}\cdot\text{cm}^{-2}$ ) were measured by DXA using the DPX-IQ densitometer (Lunar Corporation, Madison, WI, USA) equipped with proprietary software. The procedure was conducted by a qualified radiologist. Coefficient of variation (CV) for measured body fat mass, fat-free mass, bone mass and bone mineral density values was less than 2%.

### Maximal swimming test

The  $C_s$  of swimming, peak oxygen uptake in swimming ( $\text{VO}_{2\text{peak}}$ ) and stroking parameters were assessed during an all-out 100-m front crawl test performed in 25-m swimming pool. Restricted as they were by the gas sampling devices, the swimmers started without diving from the wall and did not perform regular turning motions at the end of the lane but instead resumed swimming immediately without gliding underwater after the turn. Turns were made to the same lateral side at both ends of the pool to avoid distortion of the gas analyser's sampling line. Swimmers performed a 400-m warm-up swim, followed by a 10 min passive resting period before the 100-m all-out trial. A respiratory snorkel and valve system with low hydrodynamic resistance was used to collect breathing air samples (Keskinen et al., 2003; Rodriguez et al., 2008; Toussaint et al., 1987) and was connected to a telemetric portable breath-by-breath gas analyzer (Metamax-3B, Cortex, Leipzig, Germany) (Aspenes et al., 2009). Values were averaged for 10-s periods. The respiratory device, connected to a portable gas analyzer of similar technical characteristics (K4 b<sup>2</sup>, Cosmed, Italy) has demonstrated good validity and accuracy (Keskinen et al., 2003; Rodriguez et al., 2008) and has been used in recent published works (Barbosa et al., 2005a; Rodriguez et al., 2003). Swim performance was assessed from the time spend in seconds. The swimmers were familiarized with the snorkel by letting them swim 100-m at moderate speed with the breathing apparatus preceding the maximal trial.

Capillary blood samples for the measurement of blood lactate concentration ( $\text{La}$ ;  $\text{mmol}\cdot\text{L}^{-1}$ ) were taken

from the fingertip pre exercise and at the third (La<sub>3</sub>) and fifth (La<sub>5</sub>) minute during the recovery period (Capelli et al., 1998) and analysed using an enzymatic photometric method (Lange Microanalyzer, Lange GMBH, Berlin, Germany). The net increase of blood lactate concentration ( $\Delta\text{La}$ ) was obtained by subtracting the pre-trial value from the peak value attained during the recovery phase.

To exclude the influence of turning and starting, the average swimming velocity ( $v_s$ ; m/s) attained by each swimmer during the trial was measured over 15 m within two points 5.0 m apart from each end of the pool ( $v_s = D/t_{15}$ , where  $D = 15$  m and  $t_{15} =$  time for the 15-m distance) (Poujade et al., 2002; Zamparo et al., 2005a).

Swimming velocity and stroking parameters were measured by means of time video analysis (Huot-Marchand et al., 2005), by two independent evaluators. SR (cycles $\cdot\text{min}^{-1}$ ) was calculated as the average number of strokes completed by the swimmers during the 15-m distance (Poujade et al., 2002). One SR cycle being defined as the time between the entry of one hand until the following entry of the same hand (Huot-Marchand et al., 2005). SL (m $\cdot\text{cycle}^{-1}$ ) was calculated as the ratio between average velocity and the corresponding SR (Poujade et al., 2002). SI (m<sup>2</sup> $\cdot\text{s}^{-1}\cdot\text{cycle}^{-1}$ ) was calculated by multiplying swimming velocity by SL (Costill et al., 1985). Total energy expenditure ( $E_{\text{tot}}$ ; mLO<sub>2</sub> $\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) corrected for body mass was calculated using the net VO<sub>2</sub> (i.e. difference between the value measured at the end of the 100 m trial and the resting value), and the oxygen energy equivalent of net blood lactate concentration (i.e. difference between the value measured at the end of the task and the resting value) (Rodriguez 1999). The VO<sub>2</sub> energy equivalent was assumed to be 2.7 mLO<sub>2</sub> $\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , as that proposed by di Prampero et al. (1978) for competitive swimming.  $C_s$  was calculated as the ratio between  $E_{\text{tot}}$  and  $v_s$

(mLO<sub>2</sub> $\cdot\text{m}^{-1}$ ), and then converted into the SI units (kJ $\cdot\text{m}^{-1}$ ) by assuming that 1 mLO<sub>2</sub> is equivalent to 20.1 J (di Prampero et al., 1986; Pendergast et al., 2003).

### Statistical analysis

The normality of distribution was assessed on all data using the Kolmogorov-Smirnov test. Means, standard deviations, minimum and maximum values were calculated for all parameters (Table 1). Partial correlation coefficients ( $r_p$ ) with age as control variable were used to determine the degree of association between assessment variables and swimming performance. For each type of assessment backward stepwise linear regression analyses were used to assess the potential relationships with swimming performance and to evaluate which group of parameters (i.e., anthropometrical, physiological, biomechanical) best characterized swimming performance. Additionally, multiple linear regression (MLR) models using the backward stepwise procedure were developed entering all variables.

A  $p$ -value  $\leq .05$  was considered to be statistically significant. SPSS for Windows, version 13.0; (SPSS Inc.; Chicago, IL) was used for all analyses.

### Results

Mean ( $\pm$  SD) 100-m performance time was  $77.6 \pm 9.1$  s. The average  $v_s$  without gliding start and turnings was  $1.34 \pm 0.14$  m $\cdot\text{s}^{-1}$ . Descriptive statistics for anthropometrical, physiological and biomechanical parameters and their relationship with 100- front crawl performance time with age as control variable are presented in Table 1. Partial correlation analysis showed that swimming performance was significantly correlated ( $p < .05$ ) with body height, bone mass, spine bone mineral density and arm span

**Table 1.** Anthropometrical, physiological and biomechanical parameters and their correlate with 100-m front crawl swimming performance in adolescent swimmers ( $n = 25$ ). Data are means ( $\pm$  standard deviations, SD), minimal and maximal values, and partial correlation coefficients ( $r_p$ ) with age as control variable.

Variable	Mean (SD)	min	max	Partial correlation with 100-m time ( $r_p$ )
Body height (cm)	1.76 (.09)	1.52	1.89	-.536 *
Body mass, BM (kg)	63.3 (10.9)	45.0	89.0	-.480
Body mass index, BMI (kg $\cdot\text{m}^{-2}$ )	20.2 (2.2)	15.6	24.9	-.247
Body fat (%)	12.8 (3.3)	7.5	18.4	.061
Total body fat mass, (kg)	8.0 (2.2)	4.1	11.6	-.174
Fat-free mass, (kg)	54.7 (9.6)	39.0	77.4	-.506
Bone mass, (kg)	2.7 (.6)	1.60	3.84	-.543 *
Total bone mineral density, (g $\cdot\text{cm}^{-2}$ )	1.12 (.10)	.95	1.33	-.462
Spine bone mineral density, (g $\cdot\text{cm}^{-2}$ )	1.06 (.15)	.79	1.28	-.516 *
Arm span (cm)	182.8 (11.5)	152.5	200.5	-.557 *
Velocity, $v_s$ (m $\cdot\text{s}^{-1}$ )	1.34 (.14)	1.01	1.57	-.938 *
Stroke length, SL (m $\cdot\text{cycle}^{-1}$ )	1.00 (.09)	.84	1.22	-.506
Stroke rate, SR (cycle $\cdot\text{min}^{-1}$ )	40.2 (2.9)	35.0	46.0	-.785 *
Stroke index, SI (m <sup>2</sup> $\cdot\text{sec}^{-1}\cdot\text{cycle}^{-1}$ )	1.35 (.24)	.85	1.83	-.643 * <sup>1</sup>
VO <sub>2peak</sub> (L $\cdot\text{min}^{-1}$ )	3.51 (.82)	2.31	5.72	-.398
VO <sub>2peak</sub> (ml $\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ )	55.2 (5.9)	44.4	70.6	-.017
$\Delta\text{VO}_2$ (L $\cdot\text{min}^{-1}$ )	3.02 (.79)	1.86	5.31	-.322
La <sub>3</sub> (mmol $\cdot\text{L}^{-1}$ )	6.40 (2.81)	2.64	14.20	-.525 *
La <sub>5</sub> (mmol $\cdot\text{L}^{-1}$ )	6.58 (3.03)	2.65	14.20	-.574 *
Blood lactate accumulation, $\Delta\text{La}$ (mmol $\cdot\text{L}^{-1}$ )	4.9 (3.0)	0.61	12.6	-.598 *
Energy cost of swimming, $C_s$ (kJ $\cdot\text{m}^{-1}$ )	3.99 (1.78)	1.31	8.50	-.544 *
Tanner sexual maturation stage (1-5)	3.9 (1.02)	2	5	-.285

\* Statistically significant correlation ( $p \leq .05$ ); <sup>1</sup> controlled also for swimming velocity

**Table 2.** Backward stepwise linear regression analyses to assess the potential relationships with swimming performance and to evaluate which group of parameters (i.e., anthropometrical, physiological, biomechanical) best characteriz swimming performance. Multiple linear regression (MLR) models using the backward stepwise procedure were developed entering all variables.

Variables	Variables entered in model	R <sup>2</sup>	Adjusted R <sup>2</sup>	t	p	F	p
<b>Biomechanical</b>	SR, SI	.911	.903	19.902	.000	(2;24) = 112.87	.000
<b>Anthropometrical</b>	Arm span, height, bone mass, spine bone mineral density	.559	.458	4.115	.001	(4;16) = 5.503	.012
<b>Physiological</b>	$\Delta$ La, La <sub>3</sub> , La <sub>5</sub> , C <sub>s</sub>	.551	.452	4.558	.000	(4;22) = 5.531	.004
<b>In all variables</b>	SR, SI	.936	.926	16.867	.000	(2;15) = 94.412	.000

(anthropometrical parameters), SR and SI (biomechanical parameters), and C<sub>s</sub>, La<sub>3</sub>, La<sub>5</sub> and  $\Delta$ La (physiological parameters). SL was correlated with v<sub>s</sub>, but not with 100-m.

Multiple linear regression analysis demonstrated that SI (R<sup>2</sup> = 0.788; p = 0.000), arm span (R<sup>2</sup> = 0.485; p = 0.001), and  $\Delta$ La (R<sup>2</sup> = 0.317; p = 0.003) were the best overall predictors of 100-m performance in adolescent swimmers, respectively. Thus from this analysis, it appeared that biomechanical factors, that were entered into the model (Table 2) characterized best the 100-m swimming performance in these adolescent swimmers (90.3%; p < 0.05), followed by anthropometrical (45.8%; p < 0.05) and physiological factors (45.2%; p < 0.05). Only these parameters were entered to the models that were significantly related to swimming performance. Multiple linear regression model for all related variables with 100-m swimming performance indicated that two biomechanical parameters (SI and SR) explained 92.6% of the variance (Table 2).

Additionally, as C<sub>s</sub> was related to swimming time, we evaluated the possible contribution of different parameters to C<sub>s</sub>. Partial correlation analysis showed that C<sub>s</sub> was significantly related to v<sub>s</sub> (r = .576; p = .025), La<sub>3</sub> (r = .580; p = .000), La<sub>5</sub> (r = .632; p = .000) and  $\Delta$ La (r = .646; p = .000), but not to VO<sub>2</sub> (r = .377; p = .833) or  $\Delta$ VO<sub>2</sub> (r = .288; p = .072).

## Discussion

This study investigated the contribution of different anthropometrical, physiological and biomechanical parameters to sprint swimming performance in adolescent boys. The main findings are: 1) that biomechanical factors may explain 90.3% of the variance in 100-m swimming performance 2) that anthropometrical (45.8%) and physiological (45.2%) parameters were also strongly related to 100-m performance 3) that the best single performance predictors were SI, arm span and  $\Delta$ La; and 4) that two selected variables included in the MLR model for all variables (SI and SR) explained 92.6% of the variance in 100-m swimming performance in this adolescent swimmers.

Few studies have investigated the relationship of different biomechanical and physiological parameters to 100-m front crawl performance in adolescent swimmers (Kjendlie et al., 2004a; 2004b). Swimmers start heavy trainings at relatively young age therefore, it is important to assess which parameters may be the best predictors of sprint swimming performance. This enables consideration

of specific parameters when predicting success and planning specific training programs in young swimmers.

The obtained SR values (40.1 ± 2.8) were in relatively same range as found in other studies (Dekerle et al., 2002; Fernandes et al., 2008; Strzala and Tyka, 2009). However, even SL parameters can not be easily compared since most studies have not used respiratory snorkel that, due to some resistance, has the impact on SL. In elite swimmers using respiratory snorkel, SL was significantly higher compared to our study (Dekerle et al., 2005; Fernandes et al., 2008). However, their subjects were also significantly older (19 years vs 15 years, respectively). The present investigation showed that biomechanical parameters (SI and SR) are close correlates of 100-m swimming performance, SI being the best single predictor of 100-m swimming performance in these adolescent male swimmers. Previous studies have shown that SI is strongly related to swimming performance in adolescent swimmers also in longer distances (Jürimäe et al., 2007; Lätt et al., 2009a; 2009b), as well as a good predictor of overall competitive performance (Saavedra et al., 2010). Therefore, it seems important to emphasize the importance of teaching and learning the correct swimming technique from the early years of swimming training, regardless of the event. Marinho et al., 2010 also recommended that specific training sets concerning technique correction and improvement in young swimmers might be a main aim during training planning in swimming.

C<sub>s</sub> is one of the commonly used parameter to predict the swimming performance (Kjendlie et al., 2004a; Poujade et al., 2002; Zamparo et al., 2005b). In this study we measured VO<sub>2</sub> using modern procedures for collecting and measuring breath-by-breath expired gas, which allowed the characterization of VO<sub>2</sub> kinetics during swimming exercise. This method has been found suitable for assessing swimming performance in young swimmers (Keskinen et al., 2003; Kjendlie et al., 2004a; Ratel and Poujade, 2009; Rodriguez et al., 2008). VO<sub>2</sub> parameter at similar age subjects has not been extensively studied. The obtained VO<sub>2peak</sub> values in this study were in the same range as in Strzala et al. (2005), where VO<sub>2</sub> values were measured during 100-m distance in adolescents Tanner stage 4-5. However, they measured oxygen consumption on cycle ergometer (Strzala et al. 2005). Two other studies (Dekerle et al., 2005; Fernandes et al., 2008) measured VO<sub>2</sub> in the pool, but their subjects were older (19 years old) and at higher level, that resulted in high VO<sub>2peak</sub> values (> 70 ml·min<sup>-1</sup>·kg<sup>-1</sup>). C<sub>s</sub> is a key parameter to evaluate performance in swimming, but there are only a few studies that have investigated the determinants of C<sub>s</sub> in

children and adolescents (Kjendlie et al., 2004a; Poujade et al., 2002). Previous investigations have found relationships between  $C_s$  and body height, body mass and arm span in adolescent swimmers (Jürimäe et al., 2007; Läht et al., 2009b; Ratel and Poujade, 2009), but this was not the case in our study, where no relationships between anthropometrical parameters and  $C_s$  were found.

In sprint swimming  $v_s$  seems to depend mainly on anaerobic capacity and swimming efficiency in adolescent swimmers (Strzala and Tyka, 2009), although peak  $\dot{V}O_2$  has also been found to significantly correlated with 100-m speed ( $r = .787$ ) in adult swimmers (Rodríguez et al., 2003). In our study  $C$  was significantly related to  $La_3$ ,  $La_5$  and  $\Delta La$ , but not to  $\dot{V}O_{2peak}$  or  $\Delta \dot{V}O_2$  value. This may be explained by the fact that  $C_s$  is calculated based on both aerobic and anaerobic energy expenditure (Barbosa et al., 2005b; 2006; di Prampero et al., 1986). We suggest that swimming in our study was performed quite extensively in anaerobic zone and thus general  $C_s$  relied mostly on the anaerobic energy metabolism. The fact that  $C_s$  is related to the  $\dot{V}O_2$  may be due to the role of the anaerobic processes to the total energy expenditure, which is not always taken into account or is obviously less important when longer distances are used. The relative contribution of this bioenergetical system to the overall energy expenditure should not be disregarded (Camus and Thys, 1991). Strzala and Tyka (2009) also found that a large contribution of anaerobic energetic processes in sprint efforts leads to high post-exercise blood lactate concentration. Sprint events are heavily reliant on the anaerobic energy processes, but children's ability to generate energy via this system is limited (Taylor et al., 2003), therefore  $C_s$  was probably not related to 100m front crawl sprint performance. By investigating how anaerobic performance develops during growth and maturation, it may be possible to identify the capacity for improvement and provide guidelines to coaches for the preparation of specific training sessions for young swimmers.

In this study, biomechanical parameters were closely related to 100-m swimming time and SI was the best predictor of performance. SI is an index of swimming technical efficiency, since higher values denote that the swimmer covers a given distance with fastest time and with less number of strokes. We found a direct relationship between swimming time and  $v_s$ , as expected, and an inverse relationship with SR, which is in accordance with previous studies (Barbosa et al., 2005a; Strzala and Tyka, 2009; Vorontsov and Binevski 2003). Contrary to reports proving that front crawl swimming results are most strongly correlated with SL in elite adult swimmers (Arellano et al., 1994; Kennedy et al., 1990), we did not find a significant relationship between SL and swimming time. Instead, sprint swimming performance in young swimmers seem to be dependent on SR and its maintenance on relatively stable level (Alberty et al., 2005; Potdevin et al., 2006; Seifert et al., 2007) and on higher and stable increase of SL (Seifert et al., 2007). It is worthy to note, though, that swimming technique could have been affected by the breathing apparatus despite previous familiarization, since swimmers need to perform the test with some discomfort and could not turn their head (and

probably their rolling motion was also reduced) or perform regular turns.

Previous reports have found that sprint swimming performance is related to body mass, lean body mass, body height and arms span (Geladas et al., 2005; Grimston and Hay, 1986; Jürimäe et al., 2007, Silva et al., 2007). In our study, 100-m front crawl swimming time was significantly related to body height and arm span. The consistent relationship between height and swimming performance could be explained by the fact that taller swimmers seem to glide better through the water (Geladas et al., 2005; Toussaint and Hollander, 1994) and taller swimmers usually show a larger arm span, which benefits swimming efficiency (i.e. larger stroke length) (Saavedra et al., 2010). The significant correlation between 100-m performance and arm span, consistent with a previous reports (Geladas et al., 2005; Saavedra et al., 2010), suggests that the length of the upper extremities and shoulders width combined may be related with biomechanical factors relevant to propulsion.

We must acknowledge certain limitations of our study. Firstly, as previously discussed, stroking parameters and 100-m performance could have been affected by the modifications imposed by the breathing apparatus used for  $\dot{V}O_2$  measurements (head turning, body rolling, breathing rate, turns, etc.). Previous familiarization seems an important requirement and, additionally, swimmers should be instructed to minimize modifications in their technique. Secondly, it cannot be discarded that certain correlations with sprint performance, as in fact also evident in previous reports, could have been biased by covariance. Such may be the case of SI (i.e. the best predictor of performance), which, by definition, depends on  $v_s$  and  $C_s$ , which is computed from  $\Delta La$  energy equivalent. Thirdly, the seventh minute post exercise lactate concentration was not measured, which could have had influence to peak lactate values for some subjects. However, the increase from third to fifth minute post lactate concentration was relatively small and not statistically significant therefore, the possible influence of seventh minute post lactate value would have had very small influence.

## Conclusion

Present results indicate that biomechanical factors (90.3%) explained most of 100-m front crawl swimming performance variability in these adolescent male swimmers, followed by anthropometrical (45.8%) and physiological (45.2%) parameters. SI was the best single predictor of performance, while arm span and  $\Delta La$  were the best anthropometrical and bioenergetical indicators, respectively. SI and SR alone explained 92.6% of the variance in competitive performance. To take into account these results, it is of utmost importance to consider specific stroke technique parameters when predicting success in young swimmers.

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### Key points

- This study investigated the influence of different anthropometrical, physiological and biomechanical parameters on 100-m swimming performance in adolescent boys.
- Biomechanical factors contributed most to sprint swimming performance in these young male swimmers (90.3% of variability in performance), followed by anthropometrical (45.8%) and physiological (45.2%) parameters.
- Two selected variables (stroke index and stroke rate) explained 92.6% of the variance in competitive performance in these adolescent swimmers.

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